The structure of self-organized blogosphere

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In this paper, a statistical analysis of the structure of one blog community, a kind of social networks, is presented. The quantities such as degree distribution, clustering coefficient, average shortest path length are calculated to capture the features of the blogging network. We demonstrate that the blogging network has small-world property and the in and out degree distributions have power-law forms. The analysis also confirms that blogging networks show in general disassortative mixing pattern. Furthermore, the popularity of the blogs is investigated to have a Zipf's law, namely, the fraction of the number of page views of blogs follows a power law.

Introduction

The recent development of so-called network science reveals the underlying structures of complex networks and becomes the catalyst for arising common voice of interdisciplinary fields to tame the complexity [1, 2, 3, 4]. The small-world network model proposed by Watts and Strogatz quantitatively reflected that the real networks are small worlds which have high clustering and short average path length [7]. The six degree of separation, uncovered by the social psychologist Stanley Milgram, is the most famous manifestation of small-world the-The real world, however, significantly deviated from classic Erdös-Rényi model that the degree distribution is right skew, namely, follows a power law other than Poisson distribution [8, 9, 10]. In particular, for most networks, including the World Wide Web, the Internet and the metabolic networks, the degree distribution has a power-law tail — $p(k) \sim k^{-\gamma}$. Such networks are called scale free and the Barabási-Albert model (BA model) provides a possible generating mechanism for such scale-free structure: growth and preferential attachment [8]. These pioneering discoveries intensively attracted a large number of scientist from different background to plunge into this emerging immature realm. Besides, the real networks are hierarchical and have communities structure or composed of the elements — motifs [12, 13]. Nevertheless, surprisingly, it is found that the complex networks are self-similar, corresponding to the ubiquitous geometry pattern in snowflakes [11]. Meanwhile, the dynamics taking placing on complex networks such as virus spreading (information propagation), synchronization processes, games and cooperation, have been deeply investigated and well understood [6, 14, 15, 16, 17, 18, 19, 20].

The word blog is short for neologism "Web log", which is often a personal journal maintained on the Web. In

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the past few years, blogs are the fastest growing part of the WWW [21]. There are now about 20 million blogs, which are emerging as an important communication mechanism by an increasing number of people [22]. The Web in its first decade was like a big online library. Today, however, it becomes more of social web, not unlike Berners-Lee's original vision. Consequently, advanced social technologies—Blog, Wiki, Podcasting, RSS, etc, which featured as characteristics of time of Web 2.0 have led to the change of the ways of people's thinking and communicating. We refer blogistan as blog space in the jargon of the blog field. As one surfs in blogistan, the global blogistan is just like an ecosystem called blogosphere that has a life of its own. In the view of complex adaptive system, the whole blogosphere is more than the sum of its weblogs. Therefore, one can't understand the blogosphere by studying one single weblog. Moreover, some interesting phenomena corresponding to the classic ecological patterns—predators and prey, evolution and emergence, natural selection and adaptation—are ubiquitous in blogosphere, where evolutionary forces plays out in real time. For instance, individual weblogs vie for niche status, establish communities of like-minded sites, and jostle links to their sites [28]. Besides, the fascinating and powerful filtering effect, namely, collaborative filtering is created by the dynamic hierarchy of links and recommendations generated by blogs. The more bloggers there are in a particular community, the more efficient this filtering becomes, so, counter-intuitively, reducing information overload [22].

A typical blog is one long Web page on content hosting site that provides blog space. It is basically a large queue with additions appearing at the top of the page and older material scrolling down, often partitioned into archives and with links to other blogs within the same host site (internal links) or to URLs in the Web (external links). Sometimes, personal blogs could cite paragraphs of other blogs, often embedded with links that could be collected by the blog hosting sites and return feedback to the original bloggers (the term trackback is used in the blog community). At first glance, blogs are apparently nothing more than common Web pages.

Nevertheless, active blogs are updated with a frequency significantly higher than a traditional Web page, often in a bursty manner. The number and quality of links from a blog are quite different from ordinary Web pages. The links are updated more frequently by the bloggers and a significant fraction of the links are to other blogs. Furthermore, blogosphere creates an instant online communities of diverse topics for bloggers and readers who could publish their comments on blogs. Therefore it is more interactive and open than common Web pages. In this sense, the blogosphere is worth scrutinizing to reveal underlying mechanism for these interesting phenomena.

In this paper, we concentrate on the sub-ecosystem of global blogosphere: the blogs hosted by Sina which is the largest Chinese blog space provider and has about 2 million registered users in mainland of China [29]. We are interested in the emerging links pattern between Sina blogs, i.e., the collections of links to bloggers' favorite blog sites. For simplicity, the links out of the domain (http://blog.sina.com.cn) are omitted. And also, the Zipf's law in popularity of the blogs is investigated.

The remainder of this paper is organized as follows. Sec. II deals with the method of data collection, and Sec. III performs the statistical analysis of the structures of such self-organized blogosphere, including average degree, degree distribution, clustering coefficient, etc. Finally, Sec. IV lays out the conclusion and future work is presented.

Data gathering

Since there are around 20 million blogs, we focused our eyesight in a sub-community of global blogosphere—the Chinese blogs hosted on Sina. We wanted to examine the structures of such self-organized "ecosystem", including the emerging interconnected pattern of Sina blogs and the Zipf's law in popularity of blogs. This would be the first stride to explore the mysteries of vivid blogosphere.

The blog sites of Sina are very regular, the entry to blog has two equivalent forms: (a) http://blog.sina.com.cn/m/XXXX, where XXXX a string consisted of letters and numbers: http://blog.sina.com.cn/u/xxxxx, where xxxxx is a 10 digits number as user's id. For all users, they have (b) site forms of their blogs. While for advanced users, they both have (a) and (b) forms of entries to their blogs. As some bloggers' sites both have (a) and (b), the mapping relationships between (a) and (b) are established to avoid the reduplicate results. We designed a simple WWW robot which began with the most popular blog, which ranked first in global blogosphere by Technorati [30]. This popular blog's number of page views has been more than 30 million. Along with the collections of links to favorite Sina blogs, the robot crawled down a connected networks of 200, 399 nodes, using breadth-first search method. At the same time, the page views of each visited blogs were recorded down. Based upon these data, the analysis of

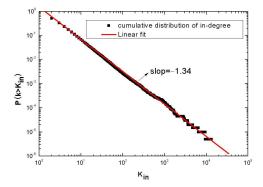


FIG. 1: (Color online) Cumulative distribution of in-degree of blogs. The straight red line is the linear fit of the data, whose slope is -1.34 ± 0.001 .

the structure of self-organized blogosphere was carried out in next section.

Results

The emerging link pattern of Sina blogs is mined from the crawled down networks. Since the nature of the network is directed, thus the connectivity of the blog has incoming and outgoing connections, namely, k_{in} and k_{out} respectively. The in-degree could be used as an index of importance of the blogs. From Fig. 1, we found that the cumulative distribution of in-degree obeys a powerlaw form, $P_{in}(k > K) \sim K^{-\alpha}$, where $\alpha = 1.34 \pm 0.001$. Therefore, the in-degree distribution, which indicates the probability that randomly chosen node i has k incoming connections, follows a power law, $P_{in}(k) \sim k^{-\gamma_{in}}$, where $\gamma_{in} = \alpha + 1 = 2.34 \pm 0.001$ [31]. The cumulative distribution of out-degree has a power-law tail as $P_{out}(k > K) \sim K^{-\beta}$, where $\beta = 2.60 \pm 0.02$ (see Fig. 2 for details). Thereby, the out-degree distribution has the form $P_{out}(k) \sim k^{\gamma_{out}}$, where $\gamma = \beta + 1 = 3.60 \pm 0.02$. By contrast, the out-degree distribution slightly deviates from the right skew heavy tail for small out-degree k_{out} . Paradoxically, someone may argue that the log-normal distribution would better fit the data than the power law. Yet, we think that there exists a threshold as certain k_{out} and when out-degree exceeds that threshold, a power-law tail exists, given the evidence that most of the data fall into the right skew tail [32].

In our collected population of inter-connected blogs, the maximum in-degree is 13,342, whereas a majority of blogs just have a few incoming links (see Tab. I). The power-law distribution of in-degree indicates that many common bloggers preferentially add links to their favorite celebrities' blogs and such preferential behavior results in the power-law distribution of the in-degree just as the BA model describes. We found that a significant fraction of the blogs, that is 32.6%, have no outgoing links to other

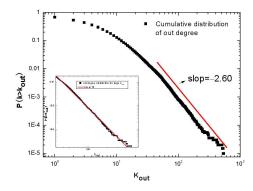


FIG. 2: (Color online) Cumulative distribution of out degree of blogs. The plotted straight red line is of slope -2.60 ± 0.02 for comparison. The insect shows the detail log-log plot of the right skew tail for large out degree. The linear fit of that data justifies that the heavy tail obeys a power law as $P_{out}(k>K)\sim k^{-\beta}$.

TABLE I: Percentage of blogs with null, 1, 2 and 3 out and in degrees. Note that a large fraction of blogs have only small in and out degrees. Since our blogging network was crawled along the directed links, the in-degree of blogs is at least 1.

k=	0	1	2	3
In	0	48.4%	18.1%	9.8%
Out	32.6%	14.2%	9.7%	7.5%

blogs. Further, considerable fraction of blogs have only a few outgoing connections (see Tab. I). That's to say, most of the bloggers are unknown to public and they are not active enough in the blogosphere (have small or null outgoing links).

The average degree $\langle k \rangle$ of such blogging network is 9.0, that's to say, for each node in such social networks has an average of 9 neighbors. Furthermore, the average in and out degrees $\langle k_{in} \rangle = \langle k_{out} \rangle = 4.5$. Although there are millions of connections presented in the social network, as aforementioned, about 28.7% of them are symmetric and most of the symmetric links are between the blogs of bloggers who get acquainted with each other in the blogosphere. So this proves that such blogging network is asymmetric one: while a node tends to link to a famous node, it is seldom the case that the famous node would link to this node either.

TABLE II: Correlation coefficients for the degrees at either side of an edge. Negative figures indicate that poorly connected nodes tend to link to highly connected nodes while positive values suggest that nodes with even connectivity are likely to connect to each other.

r	r_{in-in}	r_{in-out}	r_{out-in}	$r_{out-out}$
-0.497	-0.035	0.041	-0.034	0.113

Table II displays the correlation coefficients of different types of degree-degree correlations for the crawled down blogging network. Correlations are measured by the Pearson's correlation coefficient r for the degrees at either side of an edge as suggested by Mark Newman [24].

$$r = \frac{\langle k_{to}k_{from}\rangle - \langle k_{to}\rangle\langle k_{from}\rangle}{\sqrt{\langle k_{to}^2\rangle - \langle k_{to}\rangle^2}\sqrt{\langle k_{from}^2\rangle - \langle k_{from}\rangle^2}}$$
(1)

where k_{to} , k_{from} could be four possible combinations of in and out degrees of an edge.

Networks with assortative mixing pattern are those in which nodes with large degree tend to be connected to other nodes with many connections and vice visa. Technical and biological networks are in general disassortative, while social networks are often assortatively mixed as demonstrated by the study on scientific collaboration networks [24]. Blogging network, however, presents disasortative mixing pattern when directions are not considered. Positive mixing are shown for r_{in-out} and $r_{out-out}$ in our case. Positive r_{in-out} means active bloggers in the community (have large k_{out}) tend to associate with those who succeed in promoting themselves in the community (have high k_{in}), while a large $r_{out-out}$ suggests that the active bloggers preferentially link to each other. Internet dating community, a kind of social networks embedded in a technical one, and peer to peer (P2P) social networks are similar to our case, displaying a significant disassortative mixing pattern [25, 26].

The length of average shortest path $\langle l \rangle$ is calculated, which is the mean of geodesic distance between any pairs that have at least a path connecting them. In this case, $\langle l \rangle = 6.84$. That means on average one only needs to click 7 times from one blog site to any other blog site in the blogosphere. And the diameter D of this social networks which is defined as the maximum of the shortest path length, is 27. Because such blogging network is directed, the clustering coefficient is not easy to be computed. One way to avoid this difficulty is to make the network undirected. Firstly, the one-way connections were removed from the network; secondly, the isolated nodes were deleted from the graph. By doing so, the bidirectional graph with 122,470 nodes was obtained to compute the clustering coefficient. The mean degree of this undirected networks $k_{undirected}$ is 3.28. According to the definition of clustering coefficient in undirected network, $C_i = \frac{2E_i}{k_i(k_i-1)}$, that is the ratio between the number E_i of edges that actually exits between these k_i neighbor nodes of node i and the total number $k_i(k_i - 1)$. The clustering coefficient of the whole network is the average of all individual C_i 's. We found the clustering coefficient C = 0.1490, order of magnitude much higher than that of a corresponding random graph of the same size $C_{rand} = 3.28/122470 = 0.0000268$. Besides, the degreedependent local clustering coefficient C(k) is averaging C_i over vertices of degree k. Fig. 3 plots the cumulative distribution of C(k) from the undirected blogging network. However, it is hard to declare a clear power law

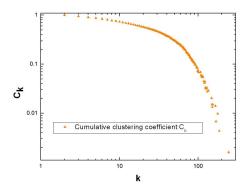


FIG. 3: (Color online) Cumulative distribution of clustering coefficient of blogs.

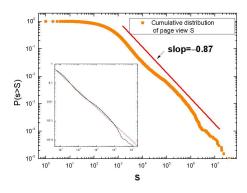


FIG. 4: (Color online) Cumulative distribution of the fraction of blogs of which the number of page views is more than S. The stright-line is of slope -0.87 for comparison with the distribution.

in our case. Nevertheless, the nonflat clustering coefficient distributions shown in the figure suggests that the dependency of C on k is nontrivial, and thus points to some degree of hierarchy in the networks. Consequently, it is demonstrated that the average shortest path length is far smaller than the logarithm of the network size in such blogging network. In addition, the network has relatively high clustering coefficient. Thence, the blogging network of inter-connected blogs has small-world effect. This small-world phenomenon is also consistent with the former small-world discovery about the WWW.

To evaluate the popularity of the blogs, the cumulative distribution of the number of page views of blog sites is figured out (see Fig. 4). For small page view S ($S \leq 500$), there exists saturation. However, for large S, the fraction of blogs that have more than total S page views obeys a power-law form as $P(s > S) \sim S^{-\tau}$, where $\tau = 0.87 \pm 6.56 \times 10^{-4}$. Immediately, one could get the distribution of page views of blogs as $p(s) \sim s^{\mu}$, where $\mu = \tau + 1 = 1.87$. In our case of 200339 nodes, only ten

blogs's page views exceed tens of millions, while most of the remanent have only tens of thousands page views. This heavy-tailed distribution indicates that most of the readers are attracted by the celebrated bloggers and contribute page views to their blogs. However, minority of the grassroots' blogs could gain public attention in the blogosphere. In this sense, some kind of inequality develops: the richer gets richer while the poorer gets poorer. Thus, social technologies not only enhance the communications between distant people, but also facilitate the inequality between the celebrated and the commons. From this respect, the blogosphere might be a good paradigm for studying the emergence of such inequality.

Conclusion remarks and future work

In summary, the sub-ecosystem of global blogosphere is scrutinized to reveal the underlying link pattern and the popularity of the blogs. We found that the blogging community has small-world property. In addition, the in-degree and out-degree distributions follow power-law forms. Calculations on degree-degree correlations show that blogging networks are in general disassortative mixing, except that active bloggers are connected between each other and by the ones with high in-degree. The fraction of number of page views of blogs also obeys a power law. Although our crawled down blogging network is static whereas the nature of blogosphere is the dynamical and evolving one, our observations and statistical analysis might be the first step to such ecosystem. However, what has been done is not enough. There are still various aspects of blogoshpere to be investigated. Recently, a new technique called collaborative tagging gains ground in blogging community because it could steer bloggers to effectively share tremendous amounts of information and find the useful information [33]. It is of some merit to study tag co-occurrence to reveal the universal characteristics of users' tagging behavior [27]. Moreover, the fascinating phenomenon of arising hot discussion topics is worth examining to dig out the intrinsic features of collective behaviors in blogosphere. And also the recommendations rules of blogging creates powerful collaborative filtering. Thus blogosphere would be the suitable one to study collaborative filtering effect. Additionally, detecting the latent community structures in blogosphere would be meaningful. And also, it is interesting to study information, like rumors, propagation in this ecosystem. In short, self-organized blogosphere is a good paradigm for understanding varieties of facets of behavior pattern of bloggers in such ecosystem.

Acknowledgments

The authors are partly supported by National Natural Science Foundation of China (NNSFC) under Grant No.10372002 and No.60528007 and National 973 Pro-

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